Data Analysis and Modeling to Support NOWCAST and Forecast Activities at the Fallon Naval Air Station

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LONG-TERM GOALS

The goals of this project are to increase our understanding of the weather predictability and develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.

OBJECTIVES

The main objectives of the study are: 1) To develop and test a mesoscale forecasting system with sub-kilometer horizontal resolution to support the NOWCAST system at the Fallon Naval Air Station (NAS); 2) To improve the accuracy of the forecasts and nowcasts by assimilating asynchronous data into the forecasting system; 3) To provide short-term predictions of cloud structure that are essential to Navy operations in the vicinity of stratus and fog decks located in irregular terrain; and 4) To develop methods of mesoscale ensemble forecasting to improve the applicability of the forecasts and nowcasts.

APPROACH

A real-time Mesoscale Model 5 (MM5) (Grell et al. 1995) system was developed as a framework for assimilation of asynchronous data, improving forecasts of clouds and fog, and adapting ensemble forecasting methods. A network of four surface weather stations was installed to provide input to the data assimilation technique for the real-time forecasting. Additionally, data from the radar wind profiler were also used to determine the optimum data assimilation for the pre-forecasting simulations.

An important component of our research is the determination of the optimum utilization of satellite data for monitoring and predicting the short-term physical characteristics of boundary layer cloud and

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thermodynamic conditions in the vicinity of the cloud top. The approach for improved identification of low cloud and fog layers is to design and test procedures to optimize the use of coincident satellite image data and numerical fields, with an initial focus on night-time conditions when the satellite data do not contain visible image information. Past datasets and methods were obtained from the DYCOMS-II (DYnamics and Chemistry Of Marine Stratocumulus-II) project (Stevens et al. 2003) and previous studies (e.g., Wetzel et al. 2001). Datasets for conditions in complex terrain are being provided by the current project for the region of central Nevada, including GOES digital data, surface mesonet observations and numerical model output.

A method has been developed to estimate cloud-top height for low-level clouds by combining the above-cloud information extracted from the satellite imagery and the below-cloud information obtained from the weather station measurements (Vellore et al. 2006). The preliminary identification of cloudy pixels is based on the surface air temperature at the NAS station (B17, see Fig. 1) and the channel 4 (11 μm) brightness temperature. Low-level clouds usually are characterized by cloud-top temperatures (CTT) above 281.15 K (8C), and this condition segregates the low-level clouds from the mid- and high-clouds. The difference between the window channel (11μm) and the shortwave IR spectral channel brightness temperature (3.9 μm) is an approximate exponential function based on cloud drop sizes and column-integrated cloud-water amounts. Smaller (greater) contrast indicates optically thin (thick) clouds. Contrast values of less than -2 K are identified as stratus clouds (Lee et al. 1997). If the cloud-top height is less than 300 m and the surface relative humidity is more than 95%, it is assumed to be fog. Optically thick low-level clouds are identified by a contrast between -2 and -0.1 K. After identifying each pixel, a simple algorithm was written to compute the cloud-top height for the entire domain. The essence of the algorithm is as follows. Using the ceilometer data and a dry-adiabatic assumption in the subcloud layer, the cloud-base height was computed. Based on the cloud-base height, the satellite-derived cloud-top temperature and the wet-adiabatic assumption, the cloud-top height was calculated. Based on this temperature, the average temperature lapse rate is determined and used to create thermodynamic profiles for the improved initial profiles and subsequent forecasts.

Regarding the methods of adapting the ensemble forecasting to high-resolution mesoscale predictions, we will consider two aspects. Firstly, we will consider the model's optional physical parameterizations with respect to a baseline run as a basis for providing ensemble elements. Secondly, we will adapt the method of perturbing initial conditions to determine the fastest growing modes of ensemble elements. These results will provide guidance on the strength of the individual or ensemble forecasts that are inputs to the nowcasting system.

WORK COMPLETED

To support real-time forecasting and nowcasting at the Fallon Naval Air Station, surface meteorological station instrumentation was procured and installed for the four locations specified through discussions with personnel at NAS Fallon and from the NOWCAST project (Fig. 1). The location specifications of these sites are:

Site Name: Fallon 31ESE [NAS B17] at Centroid in Fairview Valley (39°19'27" N, 118°13'22" W, 4235' MSL). Location from NAS Fallon: 23 miles range at 99 degrees azimuth.

Site Name: Fallon 23SSE [NAS B19] at Blowing Sand Mountains (39°08'31"N, 118°40'01"W, 3886' MSL). Location from NAS Fallon: 16 miles range at 164 degrees azimuth.

Site Name: Fallon 36NE [NAS B20] at Carson Sink (38°54'40" N, 118°23'14" W, 3881' MSL). Location from NAS Fallon: 31 miles range at 13 degrees azimuth

Site Name: Fallon NAS EW71 Complex at Edwards Creek Valley (39°31'57" N, 117°44'50" W, 5192' MSL). Location from EW Complex: 11 miles NE of Cold Springs, NV

Figure 1. Regional view of Fallon Naval Air Station with locations of four meteorological tower sites (B17, B19, B20 and EW71), in relation to highways 50, 80 and 95, and local topographic features. [See foregoing text for the location specifics.]

Each meteorological system has sensors and datalogging for wind speed and direction, humidity, station pressure and precipitation measurements as well as soil temperature. It was determined that only the B17 site has sufficient power availability to operate the ceilometer and visibility sensor, so only this location has those additional instruments. Data communication is accomplished via the NOAA NESDIS GOES Data Collection Platform (DCP) satellite transmission uplink system, and the data are accessed from NESDIS using automated retrieval from the WRCC computer system. Transmission is made at approximately 20 minutes past each hour, and includes data parameters at 10-minute observation frequency.

The real-time MM5 system was developed and installed on a XD1 Cray computer at the Desert Research Institute. To account for synoptic processes and also to resolve the characteristics of the mesoscale processes, coarse and nested grids were set up to cover a large portion of the western U.S. The coarsest grid had a horizontal resolution of 27 km and encompassed most of the eastern Pacific Ocean and the western United States; it was 103 x 103 points, centered at 39.417 N, 118.701 W. The next grid, which was 103 x 103 points with a horizontal resolution of 9 km, covered Nevada and most

of California, while the subsequent grids were each centered on Fallon, with resolutions of 3, 1, and 1/3 km. The third grid was 103 x 103, while grids 4 and 5 were both 49 x 49 points. Each model domain consists of 40 full-sigma levels. Horizontal wind components and thermodynamic variables are computed on half-sigma levels, while vertical velocity is computed on full-sigma levels. The topography input was extracted from the 30"-resolution global terrain and land use files. The main physics options included: warm-rain microphysics; the Grell cumulus parameterization; the Eta Mellor-Yamada turbulence parameterization; a cloud-radiation algorithm; and a multi-layer soil temperature model. First-guess fields and lateral boundary conditions for the coarse grid for every 12 hours are obtained from the Eta model simulation. Figure 1 shows a false-color composite image of domains 4 (1 km MM5 resolution) and 5 (1/3 km MM5 resolution). The image was obtained from the USGS Digital Elevation Map and Landsat reflectance data with common 15 m horizontal resolution (T. Minor 2006, Personal Communication). This image will be used as a background for future visualization of the real-time forecasts.

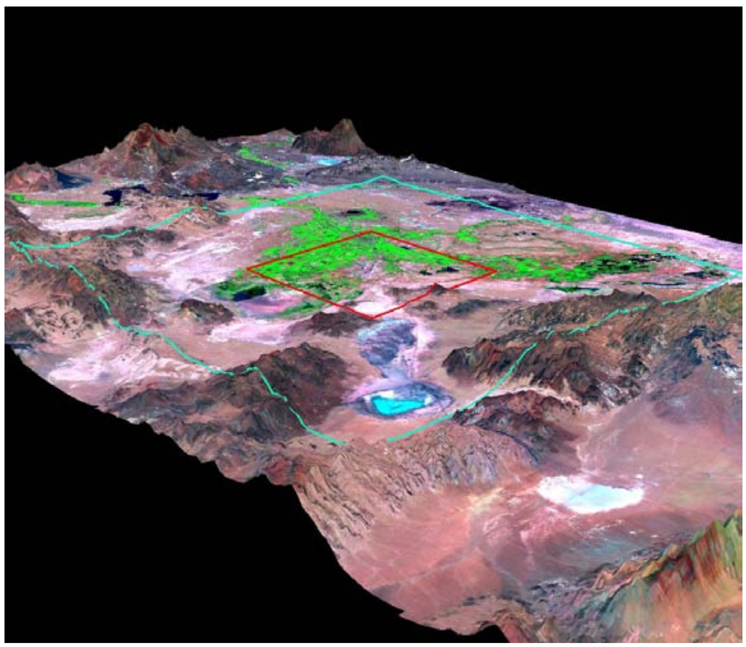

Fig. 2. False-color composite image of the MM5 real-time forecasting domains 4 and 5 with horizontal resolutions of 1 and 1/3 km, respectively. [The figure shows topographic ranges to the west and east of Fallon, NV, and the location of the NAS airport in the eastern side of the town.]

The Four Dimensional Data Assimilation technique was applied to the data from the three special-network weather stations installed by DRI. The data from the stations are continuously transmitted to DRI's Western Regional Climate Center network and processed through the main quality assurance software. These data were set up as input to the 12-hr pre-forecasting time to provide possibly better initial conditions and improvement in the initial forecasts (1-6 hrs) that are essential to the nowcasting.

Analysis has been made of aircraft, satellite and model forecast parameters for night-time cases from the DYCOMS-II program, where cloud layer depth, liquid water path and droplet size for night time conditions were estimated through a combination of satellite and numerical model parameters, and results of the methodology were compared with aircraft observations (Wetzel et al. 2005; Koracin et al. 2005). A version of this procedure modified for application to the Fallon Naval Air Station region of

complex land surface has been developed and demonstrated (Vellore et al. 2006). Satellite data were provided by the Naval Research Laboratory (Monterey) in SeaSpace TeraScan TDF digital format.

RESULTS

The results from the data assimilation show some characteristics that are important for nowcasting. According to our testing sample, it appears that the main advantage of using the FDDA is generally in the first three hours of the simulation. This was a frequent result obtained for various nudging coefficients and other model setup parameters. The analyses of the runs with and without FDDA show that the main benefit of using the data assimilation is within the first several hours of the simulations.

Possible reasons for this behavior should be further investigated. They could be related to the fact that nudging can induce imbalances in some of the model forcing that require adjustment later in the model run.

In the marine environments of the DYCOMS-II field program, where the surface boundary temperature can be estimated (on a coarse resolution) using the TRMM satellite data, the cloud liquid water path was obtained using adiabatic parcel theory. Combining GOES-observed cloud top temperatures, TRMM sea surface temperatures, and model thermodynamic profiles provided estimates of cloud layer depth, liquid water path and droplet size. In land-based environments, where the TRMM microwave retrievals are not available and there is large variability of surface boundary parameters, valuable observational data include surface air state parameters and ground-based remote sensing. Instrumentation established for the ONR-supported Fallon Naval Air Station and Naval Research Laboratory's NOWCAST project provides surface air temperature, humidity and ceilometer measurements. GOES multispectral satellite data have been utilized for the study region of central Nevada to infer the presence of low cloud during nighttime conditions. At night, only thermal infrared and near-infrared satellite observations are available. Radiative transfer modeling of the 11-3.9 micron brightness temperature difference (BTD) is used as a discriminator for the presence of low cloud, which is characterized by small droplet size (Figure 3). For example, a BTD value > 4 K is expected for fog layers with effective droplet radius less than 7 microns, while a smaller BTD value would typically be observed for a stratus cloud layer. Additional threshold and difference signatures help to separate thin high cloud from low cloud, and adiabatic assumptions are used to combine surface state and ceilometer information to derive cloud base and top heights. The resulting cloud base/height grids assimilated to the model can increase the accuracy of radiative forcing calculations within the ensuing forecast period.

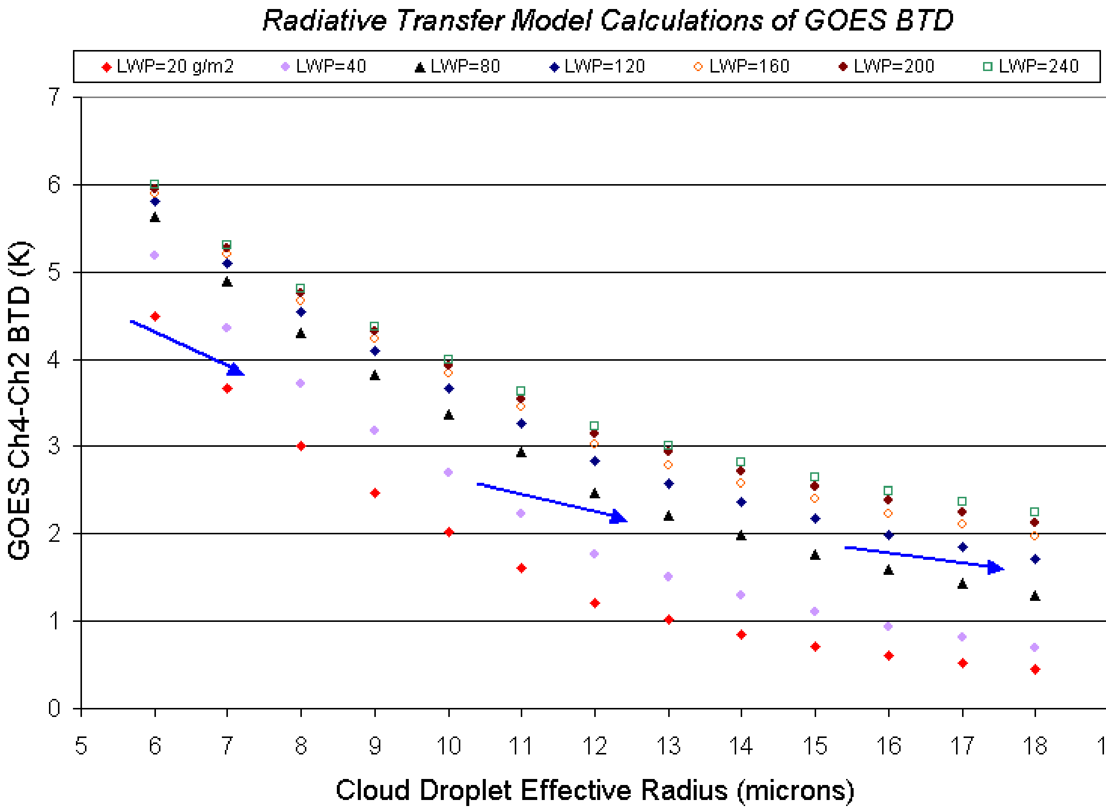

Figure 3. Radiative transfer simulations for 11 - 3.9 micron (GOES Channel 4 – Channel 2) brightness temperature difference values of stratiform cloud with varied effective droplet radius and liquid water path. [Channel 4-2 difference decreases from values of about 6K to 2K with increase of the droplet effective radius from6 to 18 microns. For each droplet radius there is a spread of channel difference values depending on the magnitude of the liquid water path (LWP).The difference is smaller by about 2 K for the drop in the LWP from 240 to 20 g/m^2.

The method of improving cloud predictions for real-time forecasting was applied to a case study on 29 June 2006 at 1200 UTC. A total of 95481 (309 x 309) pixels was considered for classification and cloud-top height computation from a single satellite image (Fig. 4).

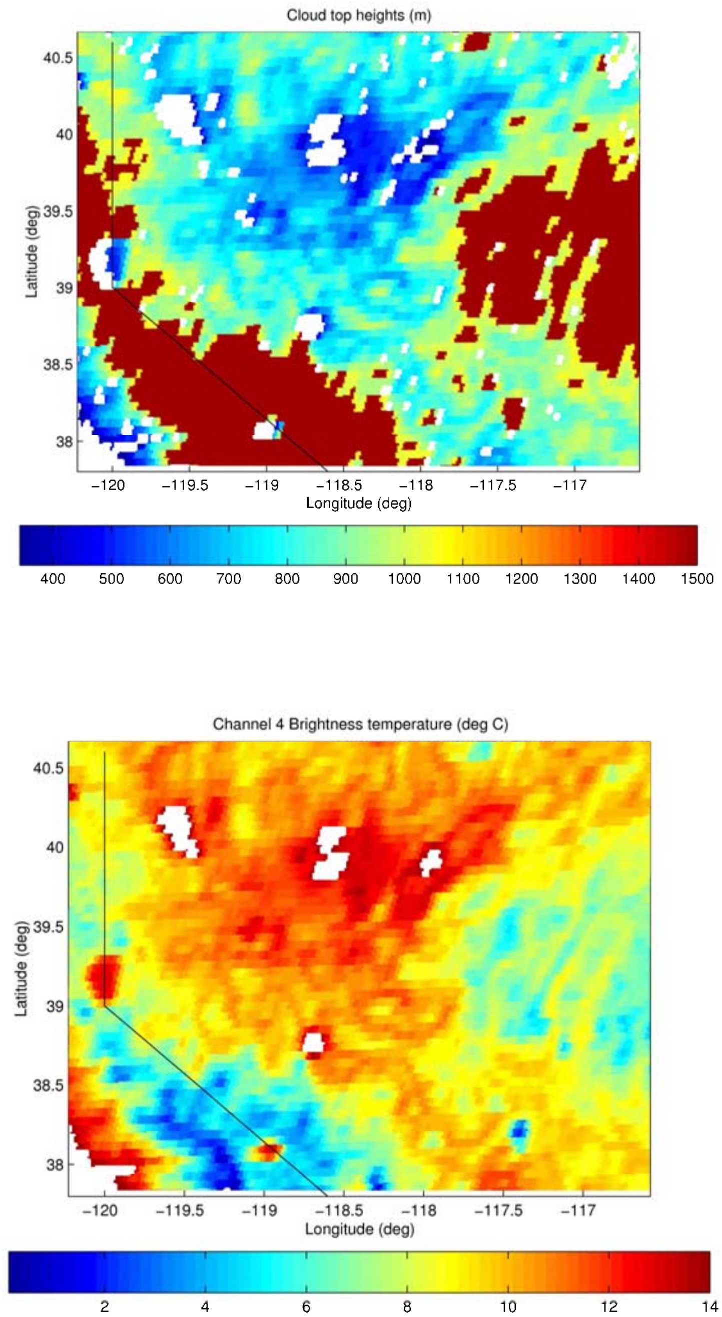

Fig. 4. Top panel: Cloud-top heights at 1200 UTC on 29 June 2006. Bottom panel: Channel 4 (11µm) brightness temperature at 1200 UTC on 29 June 2006. [Computational domain is central, western, and northwestern Nevada, and bordering areas in California. Upper panel: High clouds (tops over 1500 m) are identified in the central Nevada and along the western and southwestern border with California. Low clouds (less than 600 m) are determined to be in central and northern Nevada. Lower panel: Brightness temperature is generally less than 6ºC along the western and southwestern border with California, while the brightness temperature is generally over 10ºC in western and northwestern Nevada.]

Among these pixels, about 70% are classified in the fog and low-level cloud categories (0% fog, 8% stratus, and 62% stratocumulus) with cloud top heights ranging between 400 and 1000 m. These results are in general agreement with the Naval Research Laboratory (http://www.nrlmry.navy.mil) cloud classification. About 25% are classified in the middle-level cloud categories; 5% of the pixels are classified as no clouds, and the brightness temperatures in these pixels are comparable with the surface temperature at the B17 station.

During the first year of the project, we have examined the effects of various model physics options on the spread of ensemble forecast elements. Figure 5 shows a time series of the simulated 500 hPa height for different physics options. This parameter has been commonly used for studies of periodic and chaotic flows (Lorenz 1963).

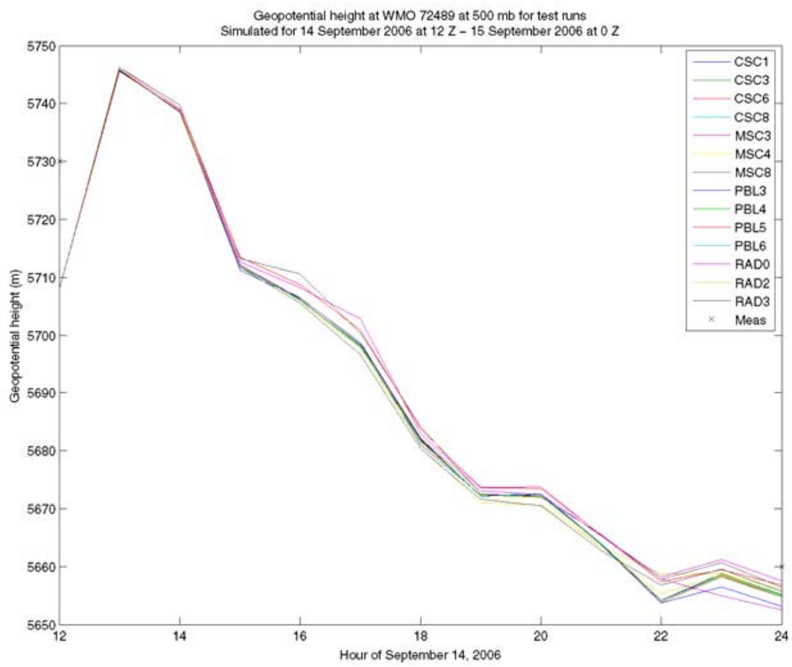

Fig. 5. Time series of the simulated 500 hPa geopotential height for various ensemble MM5 forecasting runs with different physical parameterization options. [The geopotential is maximum (5745 gpm) is at the first hour of the simulation and steadily decreases until 10 hours into the simulation where it levels off at about 5655 gpm. The differences among the various ensemble elements slowly increase after hour 3 and reach only about 5 gpm at the end of the simulation.]

The test with the 500 hPa geopotential height (Fig. 5) shows that noticeable branching starts after the third hour, but maintains similar differences among the runs until almost the end. The examination of the simulated wind speed at 3 km AGL (Fig. 6) shows much stronger variability than the geopotential height.

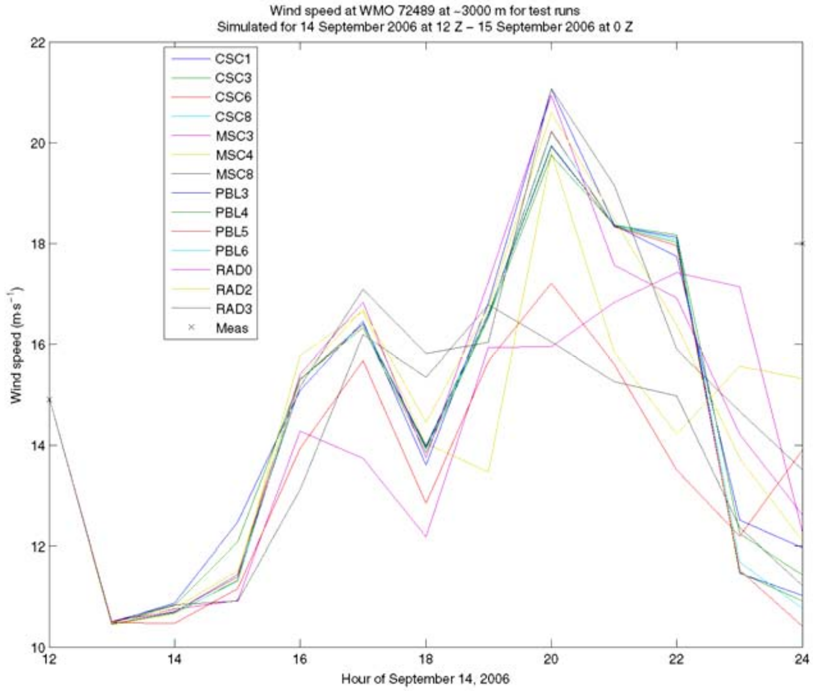

Fig. 6. Time series of the simulated wind speed at 3 km AGL for the various ensemble MM5 forecasting runs with different physical parameterization options. [The envelope of the simulated wind speed is minimum (about 10.5 ms^{-1}) at first hour and maximum at hour 5 (about 17 ms^{-1}) and hour 8 (about 21 ms^{-1}). The differences among the various runs are reaching 6 ms^{-1} near the end of the simulation.]

This analysis indicates that the wind speed is an important parameter for examining what physical options can provide the fastest modes of growth of the ensemble elements. Our results suggest that some of the physics options, in particular moisture, radiation, and turbulence schemes, should be all considered while creating the ensemble set of forecast elements. The results also show that the wind speed at various heights can be a valuable parameter in examining the efficiency of the selected ensemble forecasting elements.

RELATED PROJECTS

Dr. Koracin is a co-P.I. on ARO Project entitled "Forecasting of Desert Terrain" where real-time experience and expertise is facilitating an interdisciplinary project linking dust emission modeling, atmospheric predictions and Lagrangian Random Particle Dispersion modeling. Dr. Koracin is a P.I. on a project supported by another ARO grant that is focusing on visualization and virtual reality applications of the Fallon NAS high-resolution mesoscale forecasts. Drs. Wetzel and Koracin are also co-P.I.s on a multi-insitutional NSF-EPSCoR Project on Cognitive Information Processing: Modeling and Inversion where they are developing new methods of satellite data assimilation and investigation of precitability and chaos in numerical weather and climate forecasting.

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